Hydraulics Structures

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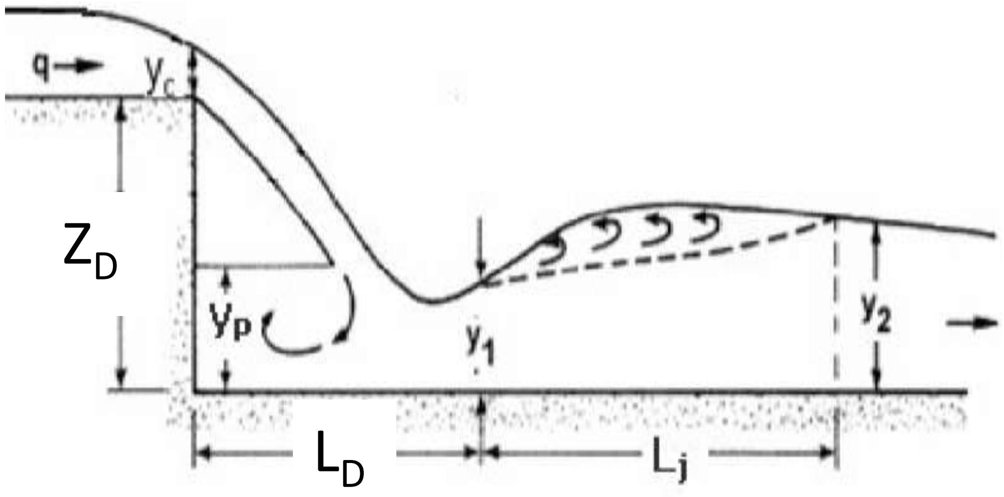
Vertical Drop

Drop structures are commonly used for flow control and energy dissipation. Changing the channel slope from steep to mild, by placing drop structures at intervals along the channel reach.

$$Drop\ Number\ ID = \left(\frac{y_c}{Z_D}\right)^3$$



Vertical Drop

$$Drop\ Number\ ID = \left(\frac{y_c}{Z_D}\right)^3$$

$$L_D = 4.3 * Z_D * ID^{0.27}$$

$$L_j = 6.9(y_2 - y_1)$$

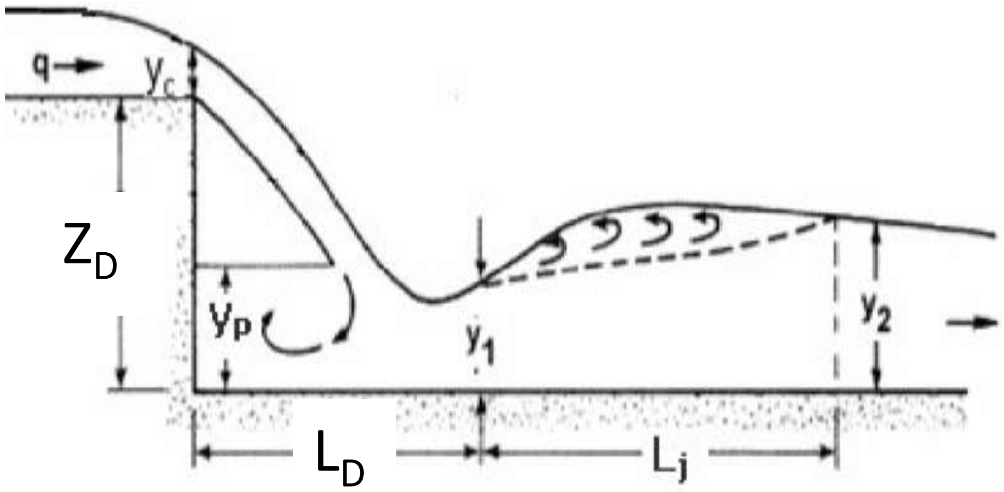
$$y_1 = 0.54 * Z_D * ID^{0.425}$$

$$y_2 = 1.66 * Z_D * ID^{0.27}$$

$$h = \frac{y_2}{6}$$

$$y_c = \frac{2}{3}\ E_{min}$$

$$y_c = \left(\frac{q^2}{g}\right)^{\frac{1}{3}}$$



Example: Design a vertical drop structure in a lined canal carrying a normal discharge of $5m^3/sec$ to lower the water from the U/S to D/S by 2m. The canal cross section in the reach's U/S and D/S of the structure are same and given below: -

Depth of flow (y) =1.4 m.

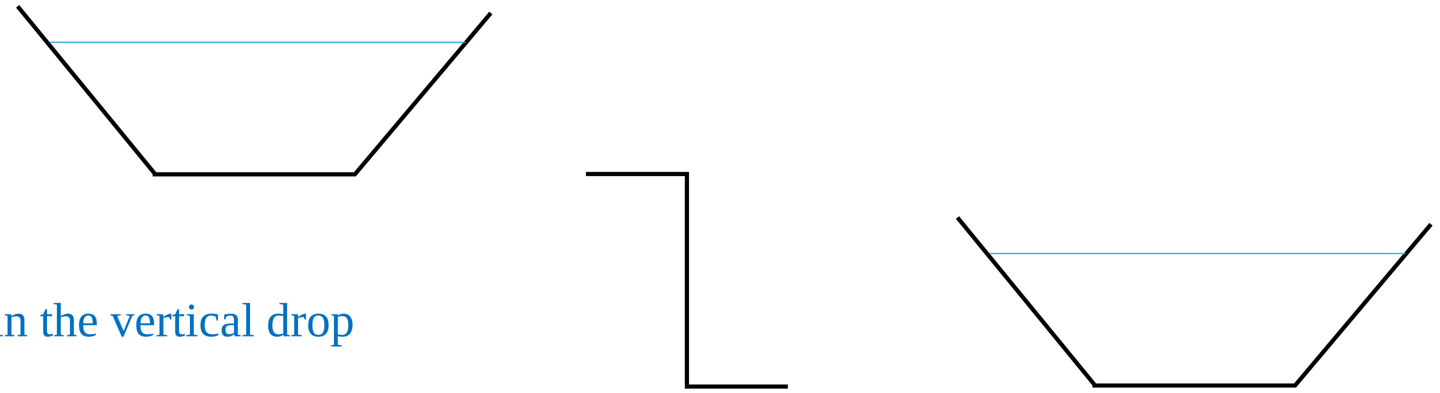
Bed width (B) = 5 m.

Longitudinal slope of the canal (S_o) = 17.7 cm/km.

Side slope of the canal (Z) = 1.5:1

Manning's coefficient (n) = 0.015.

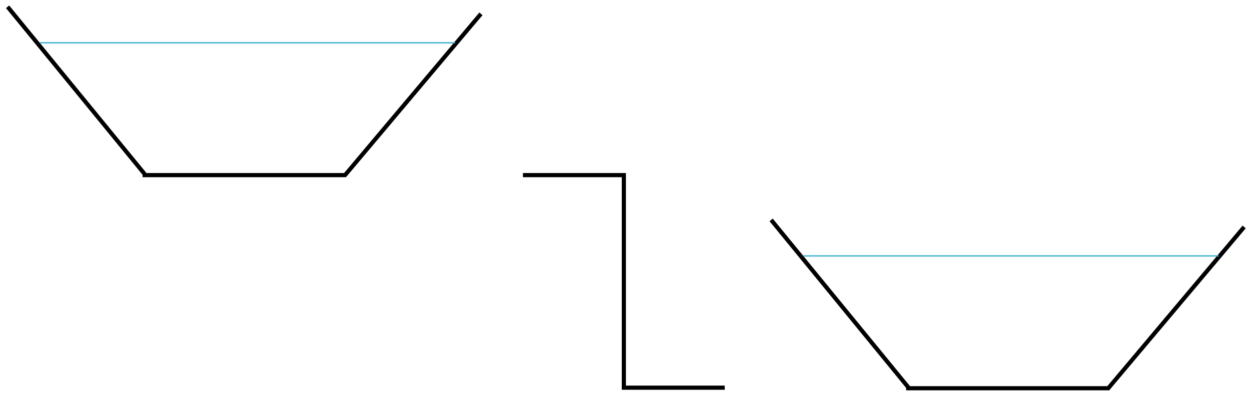
The Vertical Drop (Z_D) = 2 m.



Assume No Head loss when the water gets in the vertical drop

Solution:

For the Trapezoidal canal and when the flow at the critical depth, $\left(\frac{A^3}{T} = \frac{Q^2}{g}\right)$

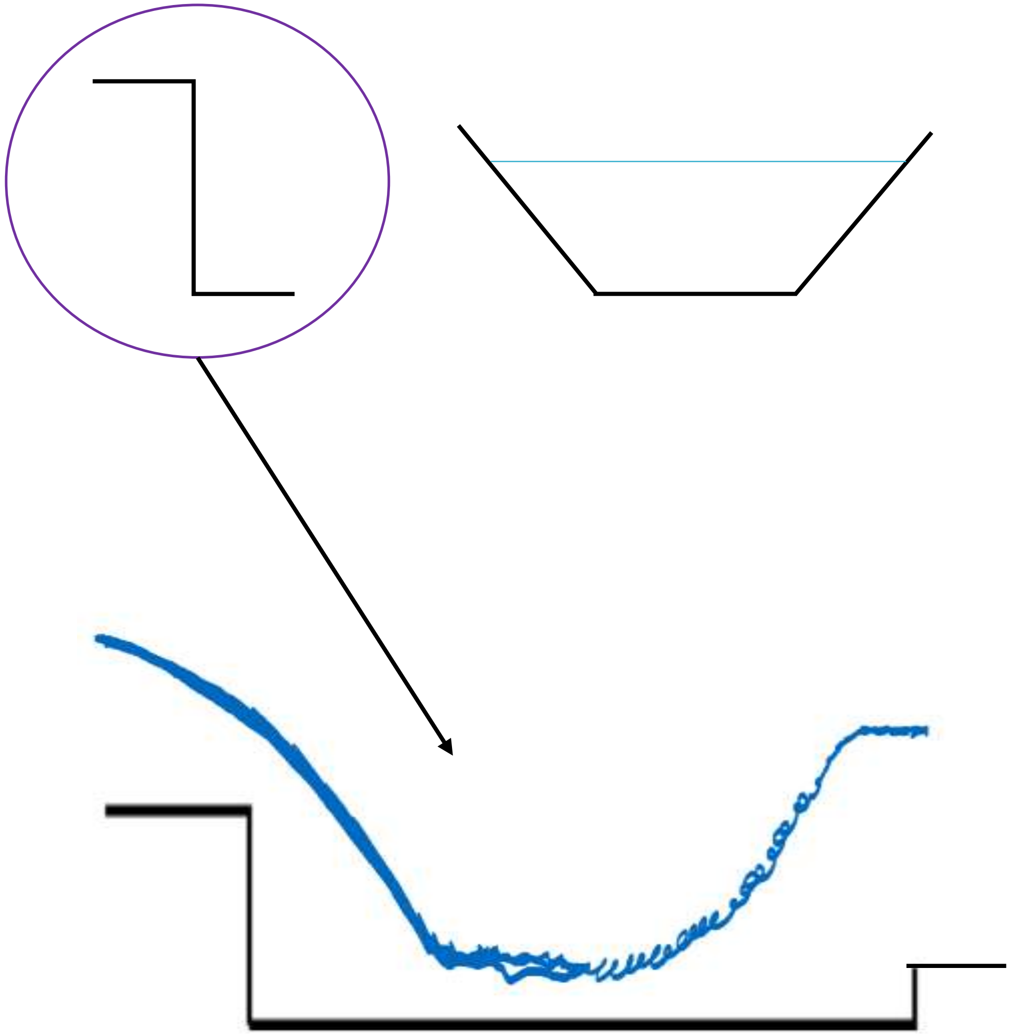


$Q = 5\ m^3/sec$

$A = By + Zy^2 \qquad \rightarrow A = 5\ y + 1.5y^2$

$T = B + 2Zy \qquad \rightarrow T = 5 + 2 * 1.5y$

By try and error, we can get the value of y that is same as y_c. $\qquad y_c \approx 0.5$ m.



$$Drop\ Number\ ID = \left(\frac{y_c}{Z_D}\right)^3 = \left(\frac{0.5}{2}\right)^3 \quad \rightarrow ID = 0.016$$

$$y_1 = 0.54 * Z_D * ID^{0.425} = 0.54 * 2 * (0.016)^{0.425} \quad \rightarrow y_1 = 0.19\ m$$

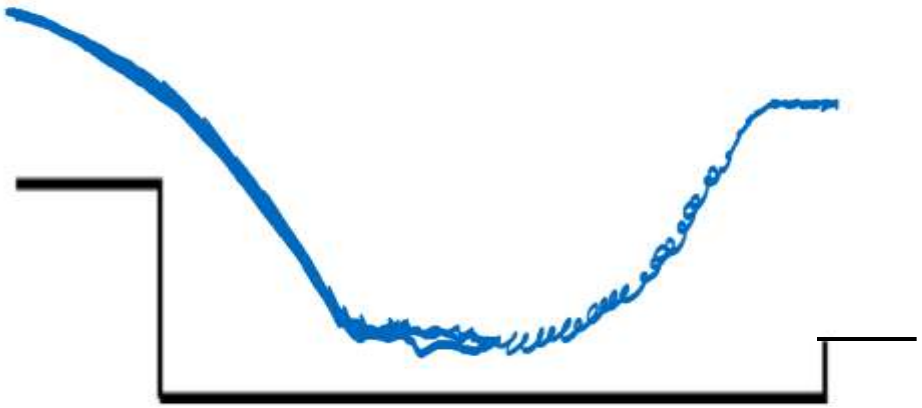
$$y_2 = 1.66 * Z_D * ID^{0.27} = 1.66 * 2 * (0.016)^{0.27} \quad \rightarrow y_2 = 1.09\ m$$

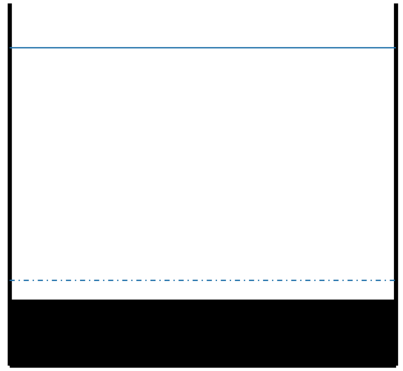
$$L_D = 4.3 * Z_D * ID^{0.27} = 4.3 * 2 * (0.016)^{0.27} \quad \rightarrow L_D = 2.82\ m$$

$$L_j = 6.9(y_2 - y_1) = 6.9(1.09 - 0.19) \quad \rightarrow L_j = 6.21\ m$$

$$L_j + L_D = 6.21 + 2.82 = 9.03\ m$$

$$h = \frac{y_2}{6} = a\frac{1.09}{6} \quad \rightarrow h = 0.18\ m$$





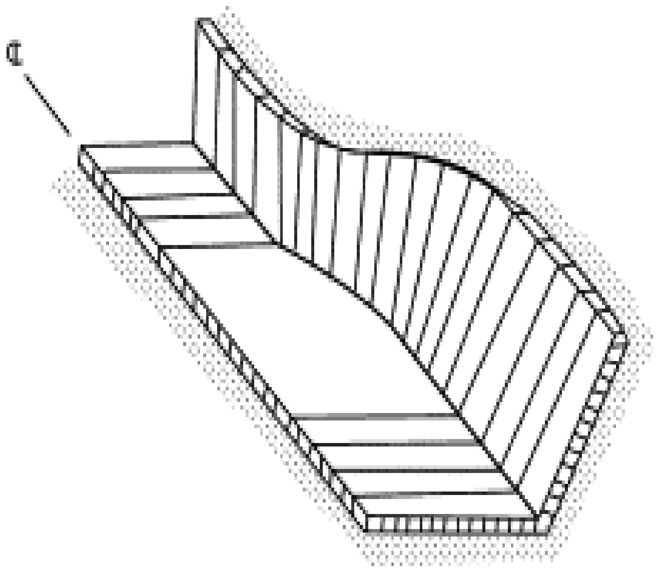
$$Q = q * S_w \qquad \rightarrow \; S_w = \frac{Q}{q}$$

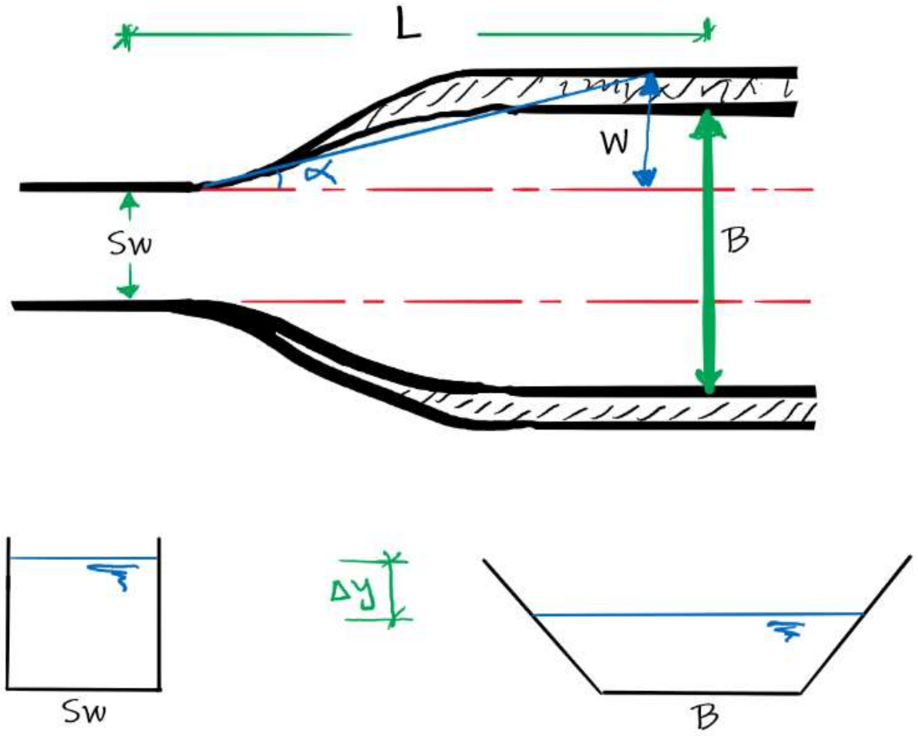
By assuming No Loss in Energy when the water gets in the vertical drop

$$y_c = \left(\frac{q^2}{g}\right)^{\frac{1}{3}} \qquad \rightarrow 0.5 = \left(\frac{q^2}{9.81}\right)^{\frac{1}{3}} \qquad q = 1.11 \frac{m^3}{sec}/m \qquad S_w = \frac{5}{1.11} \quad = \quad 4.5\ m$$

Design of Warped Transitions in Open Channels

The design water-surface profile should be a smooth, continuous curve, tangent to the water-surface profile upstream and downstream of the transition. The best approach is to first select the shape of the water surface and then to calculate the dimensions of the cross sections to conform with established principles of conservation of energy.





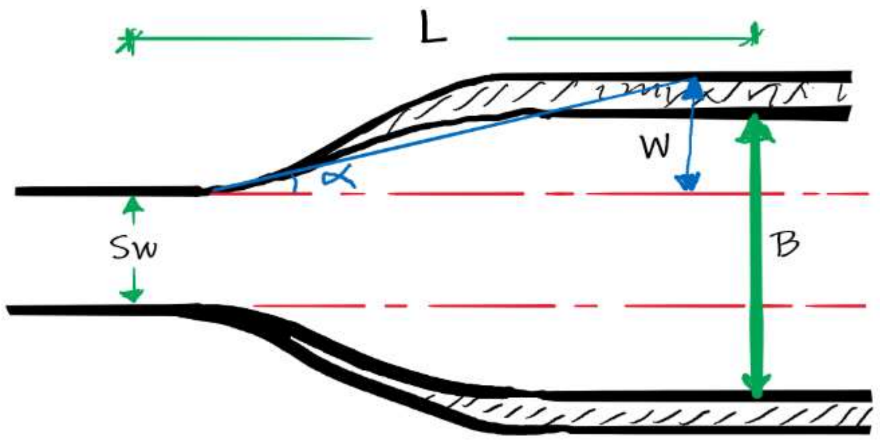
➢ ***Solution Procedure***

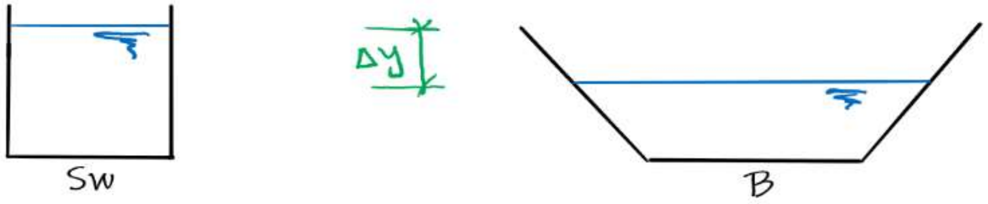
❖ Length of the transition. To determine the length of the transition, a straight line joining the flow line (on the wall) at the two ends of the transition should make an angle (θ) with the longitudinal alignment.

$$\tan(\alpha) = \frac{W}{L}$$

$$W = \frac{T}{2} - \frac{S_w}{2} = \frac{T - S_w}{2}$$

$$L = \frac{W}{\tan(\alpha)} = \frac{T - S_w}{2\tan\alpha}$$



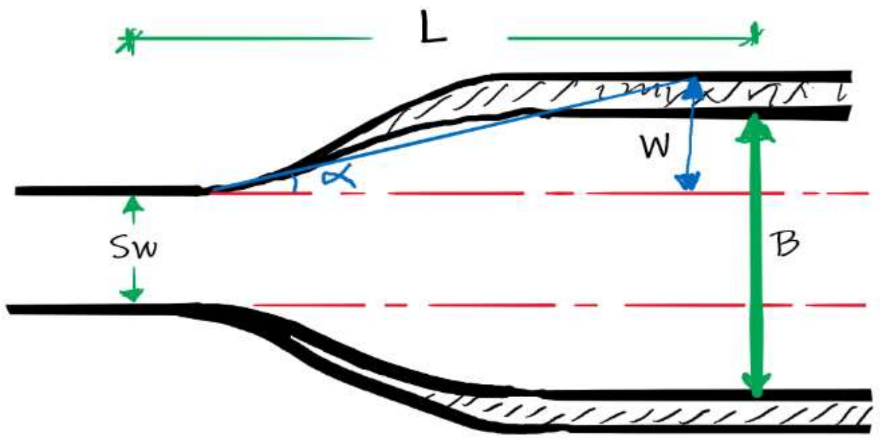


Note: The optimum angle subtended between the channel axis and a line connecting the channel sides between entrance and exit sections is 12.5°

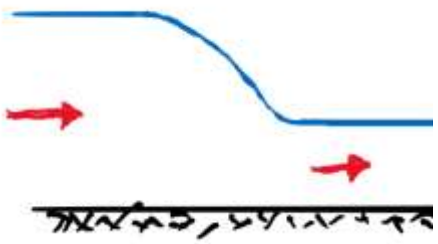
➢ ***Solution Procedure***

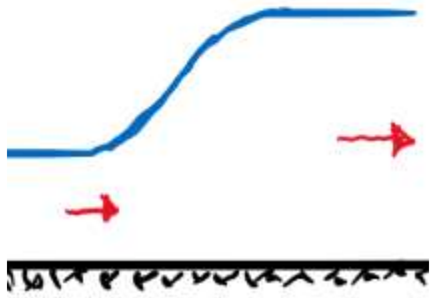
- Divide the horizontal distance (L) along the transition into equal whole number increment (ΔX).
- Calculate the drop in water-surface elevation by using the hydraulics equations.

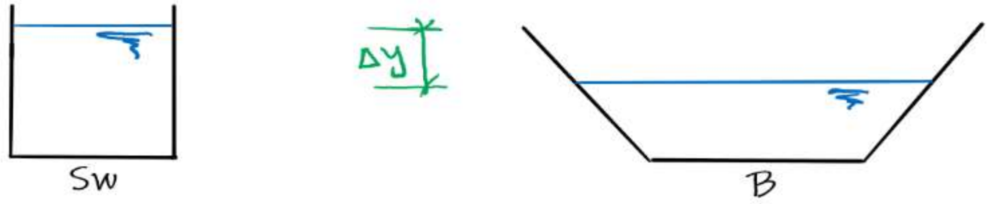
$$\Delta y^{\backslash} = (1 + k_i)\left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right) \qquad (Drop)$$



$$\Delta y^{\backslash\backslash} = (1 - k_o)\left(\frac{V_2^2}{2g} - \frac{V_3^2}{2g}\right) \qquad (Recovery)$$







➢ ***Solution Procedure***

❖ Calculate the water surface profile, equation as a parabola function $Y = CX^2$.

The boundary condition at the middle of the transition:

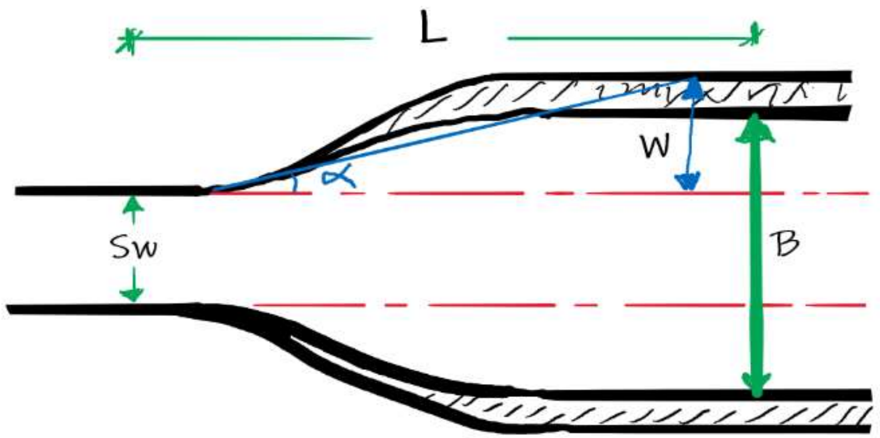
$$Y = \frac{1}{2}\Delta y \quad when \quad X = \frac{1}{2}L$$

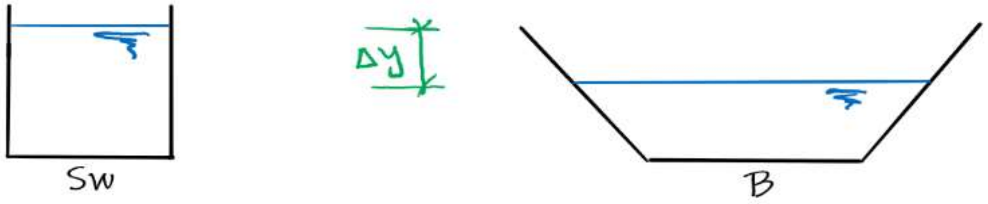
The boundary condition at the middle of the transition: (Inner Curve)

$$Y = \frac{B-S_w}{2} \quad when \quad X = \frac{1}{2}L$$

The boundary condition at the middle of the transition: (Out Curve)

$$Y = \frac{T-S_w}{2} \quad when \quad X = \frac{1}{2}L$$

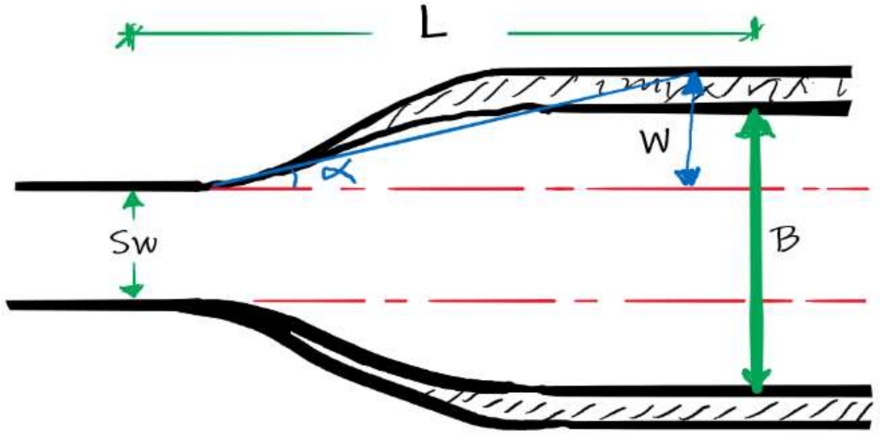




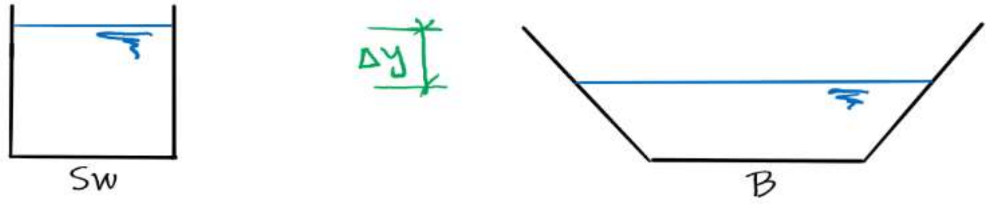
➢ ***Solution Procedure***

❖ Calculate the difference in velocity head $\Delta h_v = \frac{\Delta y\backslash}{(1+k_i)}$ or $\Delta h_v = \frac{\Delta y\backslash\backslash}{(1-k_o)}$

❖ Calculate the velocity in each section $V = \sqrt{2g\Delta h}$

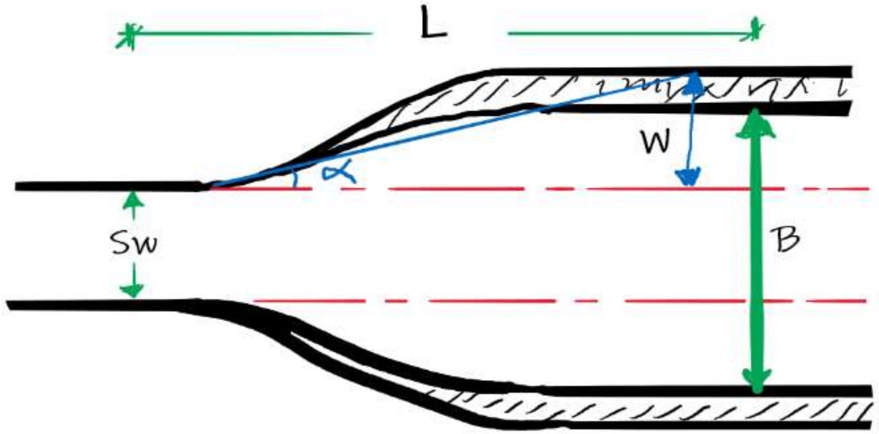


❖ Find the Area (A) in each section $A = \frac{Q}{V}$, and then estimate $\frac{B+T}{2}$



Example: Calculate and plot the required warped transition which used to contact a trapezoidal canal with a flume of rectangular. bed width of the canal 20 m, depth of water in the canal 3.5 m , 1:1 side slope. Bed width of the flume S_w= 9 m. The design discharge Q= 100 m^3/sec, α=12.5^o. Using the formula and the above curves, calculate and plot the water surface profile; K_0= 0.2; assume elevation of water in the canal equal to 10m.

<u>Solution</u>



$$A_3 = By_3 + Zy_3{}^2$$

$$A_3 = 20\ (3.5) + 1 * (3.5)^2 \quad \rightarrow \quad A_3 = 82.25\ m^2$$

$$V_3 = \frac{Q}{A} = \frac{100}{82.25} \quad \rightarrow \quad V_3 = 1.216\,\frac{m}{sec}$$

$$T = 20 + 2(3.5) = 27m$$

$$L = \frac{W}{tan\alpha}$$

$$W = \frac{T - S_w}{2} = \frac{27 - 9}{2} = 9\ m$$

$$L = \frac{9}{tan12.5^o} = 40.6\ m \ \approx 40\ m$$

$$\Delta y^{\backslash\backslash} = (1 - k_o)\left(\frac{{V_2}^2}{2g} - \frac{{V_3}^2}{2g}\right)$$

$$\Delta y^{\backslash\backslash} = (1 - 0.2)\left(\frac{{V_2}^2}{19.62} - \frac{(1.216)^2}{19.62}\right)$$

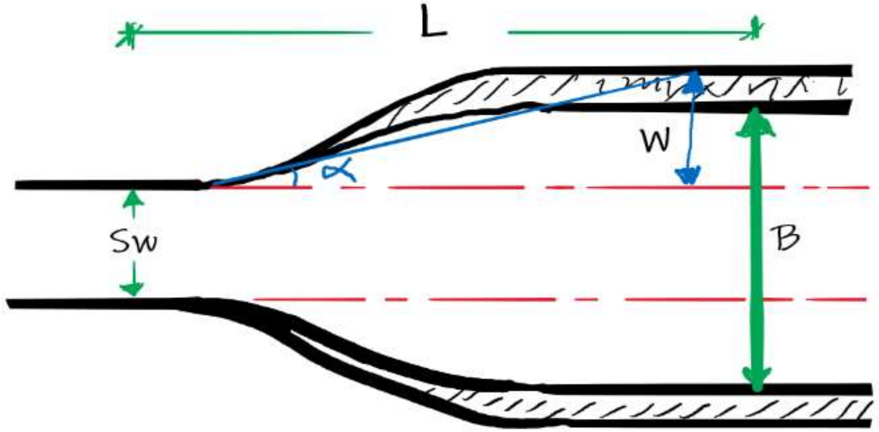
By trial and error, assume :

$V_2 = 2.5\ m/sec$, $\Delta y^{\backslash\backslash} = 0.19$

$y_2 = 3.5 - 0.19 = 3.31m$

$A_2 = S_w * y_2 = 9 * 3.31 = 29.79\ m^2$

$$V_2 = \frac{Q}{A_2} = \frac{100}{29.79} = 3.36\frac{m}{s} \neq 2.5\frac{m}{s}$$



Use $V_2 = 3.36$ *and find new* $\Delta y^{\backslash\backslash}$, *then find* y_2, *then* A_2 *and check the assumed* V_2.

Finally, $V_2 = 3.7\ m/sec$, $\Delta y^{\backslash\backslash} = 0.499$

$y_2 = 3.5 - 0.499 = 3.001m$

The equation of free surface of water is :-

$$y = C_1 X^2$$

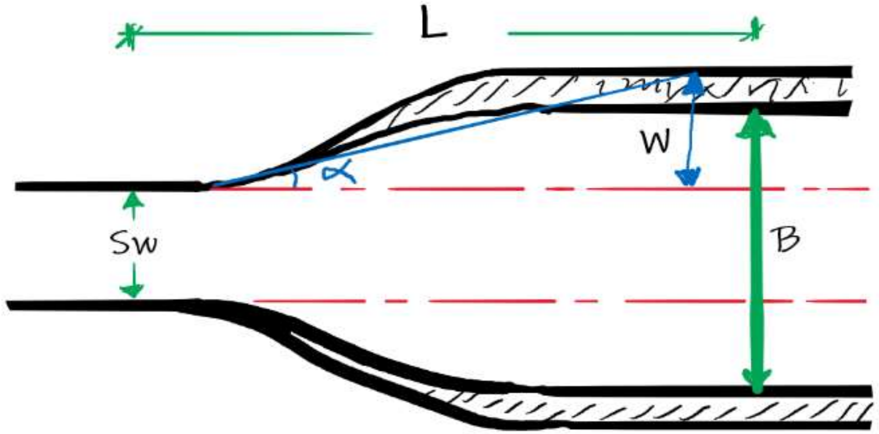
At $X = \frac{40}{2} = 20\ m$,

$$y = \frac{\Delta y^{\backslash\backslash}}{2} = \frac{0.499}{2}$$

Thus,

$$\frac{0.499}{2} = C\ (20)^2$$

$$C = 0.000624$$



The equation of free surface of water is :-

$$y = 0.000624\ X^2$$

Equation of inner curve of the transition is

$$y = C_2 X^2$$

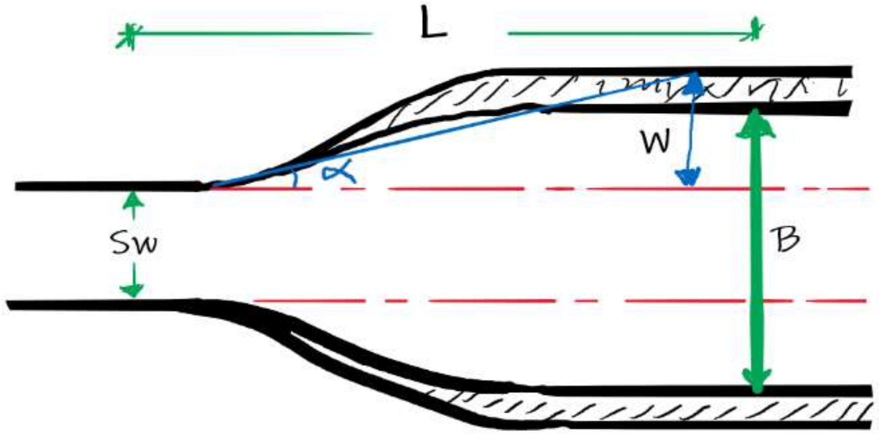
At $X = \frac{40}{2} = 20\ m\ ,\ y = \frac{\Delta y}{2}$

$$\Delta y1 = \frac{B - S_w}{2} = \frac{20-9}{2} = 5.5m$$

Thus,

$$\frac{5.5}{2} = C\ (20)^2$$

$$C = 0.006875$$



Equation of inner curve of the transition is :-

$$y1 = 0.006875X^2$$

Equation of outer curve of transition is:

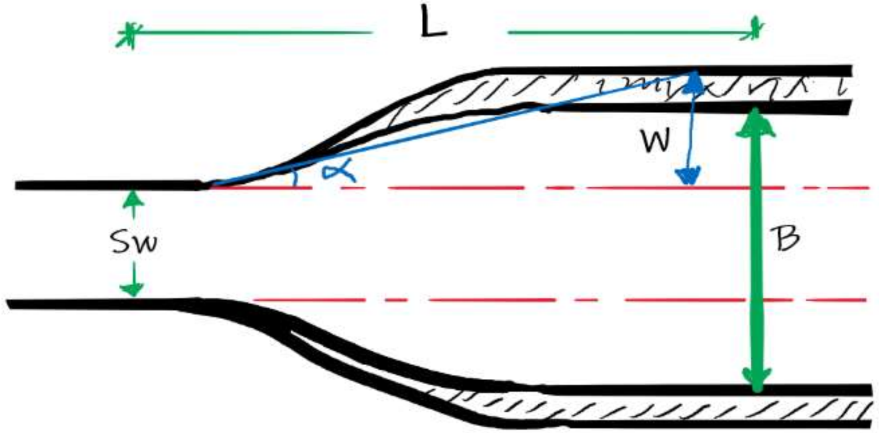
$$y = C_3 X^2$$

$$X = \frac{40}{2} = 20\ m$$

$$\Delta y_2 = \frac{T - S_W}{2} = \frac{27 - 9}{2} = 9\ m$$

$$\frac{\Delta y}{2} = \frac{9}{2} = 4.5m$$

$$4.5 = C_2\ (20)^2 \rightarrow C = 0.01125$$



The equation of outer curve is:

$$y2 = 0.01125\ X^2$$

$@\, X = 0,$ $\quad y = 0.000624\, X^2$ $\quad \Delta y^{\backslash\backslash} = 0$

$$h_{V3} = \frac{V_2^2}{2g} - \frac{\Delta y^{\backslash\backslash}}{1 - k_o} \qquad h_{V3} = \frac{(3.7)^2}{2 * 9.81} - \frac{(0)}{1 - 0.2} \qquad h_{V3} = 0.6977$$

$$V_3 = \sqrt{2 g h_{V3}} \qquad V_3 = \sqrt{2 * 9.81 * 0.6977} \qquad V_3 = 3.7 \frac{m}{s}$$

$$A_3 = \frac{Q}{V_3} \qquad A_3 = \frac{100}{3.7} \qquad A_3 = 27.02\, m^2$$

$$\frac{B}{2} = \frac{S_w}{2} + y_1 \qquad y1 = 0.006875 X^2 \qquad \frac{B}{2} = \frac{9}{2} + 0 = 4.5$$

$$\frac{T}{2} = \frac{S_w}{2} + y_2 \qquad y2 = 0.01125\, X^2 \qquad \frac{T}{2} = \frac{9}{2} + 0 = 4.5$$

$$y = \frac{A}{\frac{1}{2}(B + T)} \qquad y = \frac{27.02}{(4.5 + 4.5)} \qquad y = 3\, m$$

$@ X = 5,$ $$y = 0.000624\, X^2$$ $$\Delta y^{\backslash\backslash} = 0.0156$$

$$h_{V3} = \frac{V_2^2}{2g} - \frac{\Delta y^{\backslash\backslash}}{1 - k_o}$$ $$h_{V3} = \frac{(3.7)^2}{2 * 9.81} - \frac{(0.0156)}{1 - 0.2}$$ $$h_{V3} = 0.6782$$

$$V_3 = \sqrt{2gh_{V3}}$$ $$V_3 = \sqrt{2 * 9.81 * 0.6782}$$ $$V_3 = 3.648 \frac{m}{s}$$

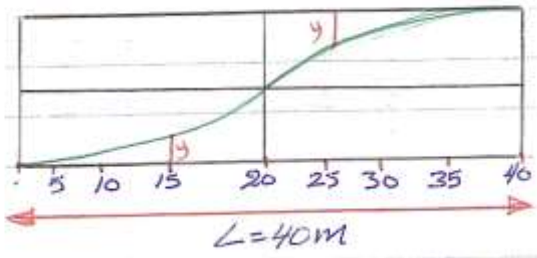
$$A_3 = \frac{Q}{V_3}$$ $$A_3 = \frac{100}{3.648}$$ $$A_3 = 27.41\, m^2$$

$$\frac{B}{2} = \frac{S_w}{2} + y_1$$ $$y1 = 0.006875X^2$$ $$\frac{B}{2} = \frac{9}{2} + 0.172 = 4.672$$

$$\frac{T}{2} = \frac{S_w}{2} + y_2$$ $$y2 = 0.01125\, X^2$$ $$\frac{T}{2} = \frac{9}{2} + 0.28 = 4.78$$

$$y = \frac{A}{\frac{1}{2}(B + T)}$$ $$y = \frac{27.41}{(4.672 + 4.78)}$$ $$y = 2.89\, m$$

Water surface		Inner curve		Outer curve						
$y = 0.000624\,X^2$		$y = 0.006875\,X^2$		$y = 0.01125\,X^2$						
X	$\Delta\bar{\bar{y}}$	Δy_1	$\frac{B - S_W}{2} + \Delta y_1$ $= 4.5 + \Delta y_1$	Δy_2	$\frac{T - S_W}{2} + \Delta y_2$ $= 4.5 + \Delta y_2$	1/2(B+T)	$h_{v3} = \frac{V^2{}_2}{2g} - \frac{\Delta\bar{\bar{y}}}{1 - K_o}$	$V_3 = \sqrt{2gh_v}$	$A = \frac{Q}{V}$	$y = \frac{A}{1/2(B+T)}$
0	0	0	4.5	0	4.5	9	0.697	3.7	27.01	3
5	0.0156	0.172	4.672	0.28	4.78	9.452	0.6782	3.648	27.41	2.89
10	0.0624	0.687	5.187	1.125	5.625	10.812	0.6197	3.487	28.65	2.65
15	0.1404	1.547	6.047	2.53	7.03	13.077	0.5223	3.205	31.2	2.38
20	0.2496	2.75	7.25	4.5	9	16.25	0.3858	2.757	36.27	2.23
25	0.3587	3.953	8.453	6.47	10.97	19.423	0.3118	2.215	45.14	2.32
30	0.4366	4.813	9.313	7.875	12.375	21.688	0.21445	1.734	57.67	2.65
35	0.4834	5.328	9.828	8.72	13.22	23.048	0.15595	1.364	73.32	3.18
40	0.499	5.5	10	9	13.5	23.5	0.13645	1.216	82.24	3.499



Water surface		Inner curve		Outer curve		$1/2(B+T)$	$h_{v3}=\frac{V_2^2}{2g}-\frac{\Delta\bar{\bar{y}}}{1-K_o}$	$V_3=\sqrt{2gh_v}$	$A=\frac{Q}{V}$	$y=\frac{A}{1/2(B+T)}$
$y=0.000624\,X^2$		$y=0.006875\,X^2$		$y=0.01125\,X^2$						
X	$\Delta\bar{\bar{y}}$	Δy_1	$\frac{B-S_W}{2}+\Delta y_1$ $=4.5+\Delta y_1$	Δy_2	$\frac{T-S_W}{2}+\Delta y_2$ $=4.5+\Delta y_2$					
0	0	0	4.5	0	4.5	9	0.697	3.7	27.01	3
5	0.0156	0.172	4.672	0.28	4.78	9.452	0.6782	3.648	27.41	2.89
10	0.0624	0.687	5.187	1.125	5.625	10.812	0.6197	3.487	28.65	2.65
15	0.1404	1.547	6.047	2.53	7.03	13.077	0.5223	3.205	31.2	2.38
20	0.2496	2.75	7.25	4.5	9	16.25	0.3858	2.757	36.27	2.23
25	0.3587	3.953	8.453	6.47	10.97	19.423	0.3118	2.215	45.14	2.32
30	0.4366	4.813	9.313	7.875	12.375	21.688	0.21445	1.734	57.67	2.65
35	0.4834	5.328	9.828	8.72	13.22	23.048	0.15595	1.364	73.32	3.18
40	0.499	5.5	10	9	13.5	23.5	0.13645	1.216	82.24	3.499

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